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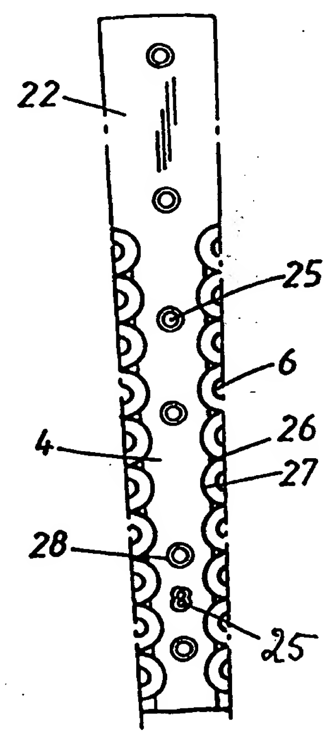
(54) Title: ROTARY ELECTRIC MACHINE WITH AXIAL COOLING

(57) Abstract

A rotating electric machine, comprising a stator (1) wound with high-voltage cable and provided with stator teeth (4) extending radially inwards in a tooth sector (18) from an outer yoke portion (22), wherein at least one stator tooth (4) is provided with an axially-running cooling duct connected to a cooling circuit (29) in which coolant (31) is arranged to circulate, and a method of cooling a rotating electric machine provided with high-voltage stator windings, where the stator winding is cooled by a coolant (31) being caused to circulate in a cooling circuit (29) through cooling tubes (25) running axially through the stator (1).



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ROTARY ELECTRIC MACHINE WITH AXIAL COOLING

TECHNICAL FIELD:
The present invention relates to high-voltage rotating electric machines, e.g., synchronous machines, but also double-fed machines, applications in asynchronous static current converter cascades, outer pole machines and synchronous flux machines, as well as alternating current machines intended primarily as generators in a power station for generating electric power. The invention relates particularly to the cooling of such machines.

BACKGROUND ART:
Rotating electric machines for high-voltages, i.e. voltages exceeding about 10 kV with the maximum of 30-35 kV, are normally arranged with a cooling system for forced cooling of the machine.

Rotating high-voltage electric machines are usually built with a stator body of sheet steel with a welded construction. The laminated core is normally made from varnished 0.35 or 0.5 mm electrical steel. The stator winding is located in slots in the sheet iron core, the slots normally having a rectangular or trapezoidal cross section. Each winding phase comprises a number of coil groups connected in series and each coil group comprises a number of coils connected in series. The different parts of the coil are designated coil side for the part which is placed in the stator and end winding for that part which is located outside the stator. A coil comprises one or more conductors brought together in height and/or width.

Between each conductor there is a thin insulation, for example epoxy/glass fibre.

The coil is insulated from the slot with a coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to earth. As insulating material, various plastic, varnish and glass fibre materials may be used. Usually, so-called mica tape is used, which is a mixture of mica and hard plastic, especially produced to provide resistance to partial discharges, which can rapidly break down the insulation. The insulation is applied to the coil by winding the mica tape around the coil in several layers. The insulation is impregnated, and then the coil side is painted

with a graphite-based paint to improve the contact with the surrounding stator which is connected to earth potential

In the case of generators, this usually must be connected to the power network via a transformer which steps up the voltage to the level of the power network - in the range of approximately 130-400 kV. The present invention is intended for use with high voltages, in the working range of 36-800 kV.

By using high-voltage insulated electric conductors, in the following termed cables, in the stator winding, with solid insulation similar to that used in cables for transmitting electric power, e.g., crosslinked polyethylene (XLPE) cables, the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional transformer can thus be eliminated. The concept generally requires the slots in which the cables are placed in the stator to be deeper than with conventional technology (thicker insulation due to higher voltage and more turns in the winding). This means that the loss distribution will be different from that in a conventional machine, which in turn entails new problems with regard to cooling, e.g., the stator teeth.

For cooling the windings of for example a synchronous machine there are three systems which can be used. With air-cooling, the winding of the stator as well as the winding of the rotor is cooled by air flowing through the windings. Air-cooling ducts are arranged in the laminated sheets of the stator as well as in the rotor. With radial ventilation and cooling by air the laminated core is, at least for medium sized and large sized machines divided in packets comprising radial and axial ventilation ducts disposed in the core. The cooling air can be ambient air but at powers above 1 MW mainly a closed cooling system with a heat exchanger is used. Hydrogen cooling is normally used in larger turbo-generators and in large synchronous compensators. The cooling method works in the same way as air-cooling with a heat exchanger, but instead of air as cooling medium hydrogen is used. Hydrogen has better cooling capabilities than air, but difficulties arise at sealings and to detect leakage. The cooling ducts are made by punching the laminated stator sheets which will constitute the

ducts when the sheet are laid for building a segment. The consequence is an increase of the pressure drop over the machine due to many small irregularities in the gas cooling ducts.

In turbo-generators of power range 500 - 1000 MW it is also known to use water cooling of the winding of the stator as well as of the winding of the rotor. The cooling ducts are made as tubes placed inside conductors in the winding of the stator. A problem in large machines is that the cooling tend to become non-uniform and, therefore, temperature variations arise in the machine.

It is considered that coils for rotating generators can be manufactured with good results within a voltage range of 3 - 25 kV.

Attempts to develop generators for higher voltages however, however, been in progress for a long time. This is obvious, for instance from "Electrical World", October 15, 1932, pages 524-525. This describes how a generator designed by Parson 1929 was arranged for 33 kV. It also describes a generator in Langerbrugge, Belgium, which produced a voltage of 36 kV. Although the article also speculates on the possibility of increasing voltage levels still further, the development was curtailed by the concepts upon which these generators were based. This was primarily because of the shortcomings of the insulation system where varnish-impregnated layers of mica oil and paper were used in several separate layers.

In a report from the Electric Power Research Institute, EPRI, EL-3391 from April 1984, an account is given of generator concepts for achieving higher voltage in an electric generator with the object of being able to connect such a generator to a power network without intermediate transformers. Such a solution is assessed in the report to offer good gains in efficiency and considerable financial advantages. The main reason that it was deemed possible in 1984 to start developing generators for direct connection to power networks was that a superconducting rotor had been developed at that time. The considerable excitation capacity of the superconducting field winding enables the use of airgap-winding with sufficient thickness to withstand the electrical stresses.

By combining the concept deemed most promising according to the project, that of designing a magnetic circuit with winding, known as "monolithe cylinder armature", a concept in which two cylinders of conductors are enclosed in three cylinders of insulation and the whole structure is attached to an iron core without teeth, it was assessed that a rotating electric machine for high voltage could be directly connected to a power network. The solution entailed the main insulation having to be made sufficiently thick to withstand network-to-network and network-to-earth potentials. Obvious drawbacks with the proposed solution, besides its demanding a superconducting rotor, are that it also requires extremely thick insulation, which increases the machine size. The end windings must be insulated and cooled with oil or freones in order to control the large electric fields at the ends. The whole machine must be hermetically sealed in order to prevent the liquid dielectric medium from absorbing moisture from the atmosphere.

Certain attempts to a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US 4,429,244 "Stator of Generator" and in Russian patent document CCCP Patent 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges. As coolant, oil is used both in the hollow conductors and in holes in the stator walls. Such cooling systems, however, entail a large number of connections of both oil and electricity at the end windings. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need of insulation of the stator winding is less towards the interior of the rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core which may increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. Special for the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centred, inside an insulation sleeve. The conductors of the stator winding are cooled by surrounding oil. The disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulation sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the duty of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional medium voltage insulated conductor with the same dimension for all the layers. The conductor is placed in stator slots formed as circular, radially placed openings corresponding to the cross-section area of the conductor and the necessary space for fixing and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulated tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the coolant against the internal air gap. The design shown has no tapering of the insulation or of the stator slots. The design exhibits a very narrow radial waist between the different stator slots, which means a large slot leakage flux which significantly influences the magnetization requirement of the machine.

EP 0342554 discloses a rotating electric machine comprising a stator cooled by liquid cooling medium. The stator of the machine is arranged with trapezoidal stator slots with corresponding cross section of winding mounted therein.

EP 0493704 discloses an electric motor comprising cooling channels in the stator teeth. The windings are in this motor arranged irregularly in the stator in slots formed between the teeth.

EP 0684682 discloses a rotating electric machine. The stator of the machine is arranged with rectangular stator slots and a winding packed with a conductor having a rectangular cross section. Axial gas cooling ducts run through the stator teeth in order to achieve heat transport from the conductors. The cooling ducts are inserted in order to cool a larger part of the radial depth of a stator tooth. This implies problems in the design of higher power machines which will contain more turns of winding and therefore deeper stator slots which result in worse mechanical stability.

EP 0155405 discloses a gas cooled arrangement for rotating dynamoelectric machine in order to improve the capacity of machines which earlier have been cooled by air to reach capacities which only water-cooled machines has.

US 2,975,309 discloses an oil-cooled stator for rotating machines, especially turbo generators. The stator of the machine is arranged with rectangular stator slots and a winding with corresponding cross-section.

US 3,675,056 discloses a hermetically sealed dynamoelectric machine connected to a fluid refrigerant circuit. The inside of the machine is filled with refrigerant flowing through ducts with triangular cross section in the stator for cooling the windings with rectangular cross-section.

US 3,801,843 discloses a rotating electrical machine having rotor and stator cooled by means of heat pipes with the aid of a two-phase fluid coolant. The stator heat pipes are located in the stator slots and extend axially to a remote location beyond the stator and the rotor. The rotor heat pipes also

serve as electrical conductors as well as heat exchangers for cooling the rotor.

OBJECT OF THE INVENTION:

The object of the present invention is to provide a cooling system for a high-voltage rotating electric machine in the range from 10 kV and up to the voltage level of the power network. Such a rotating electric machine can be directly connected to the power network without a transformer therebetween.

SUMMARY OF THE INVENTION:

The present invention relates to a means for cooling the stator teeth, and indirectly the stator winding, in a high-voltage electric machine such as a high-voltage alternating current generator.

The arrangement comprises axially-running tubes, electrically insulated, which are drawn through axial apertures through the stator teeth. The tubes are permanently glued in the apertures to ensure good cooling capacity when coolant is circulated in the tubes. The tubes run along the entire axial length of the stator teeth and are spliced in the stator ends.

According to a particularly preferred embodiment of the invention, at least one of the semiconducting layers, preferably both, have the same coefficient of thermal expansion as the solid insulation. The decisive benefit is thus achieved that defects, cracks or the like are avoided at thermal movement in the winding.

The means comprises axially running cooling tubes made of a dielectric material such as a polymer, and drawn through axial apertures in the stator yoke and in the stator teeth. The tubes are embedded in the apertures to ensure good heat transfer when coolant is circulated in the tubes. The tubes run in the stator yoke and the stator teeth, along the entire length of the stator and, if necessary, they can be spliced in the stator ends.

Polymer cooling tubes are non-conducting and the risk of short-circuiting is thus eliminated. Nor can eddy-currents occur in them. Polymer cooling

tubes can also be cold bent and drawn through several apertures without splicing, which is a great advantage.

Polymer cooling tubes can be produced from many materials such as polyethylene, polypropene, polybutene, polyvinylidene fluoride, polytetrafluoroethylene, as well as filled and reinforced elastomers. Of these polyethylene with high density, HDPE, is preferred since the thermal conductivity increases with increased density. If the polyethylene is cross-linked, which can be achieved by peroxide-splitting, silane cross-linking or radiation cross-linking, its ability to withstand pressure at increased temperature is increased at the same time as the risk of stress corrosion disappears. Cross-linked polyethylene is used for water pipes, e.g. XLPE pipes from Wirsbo Bruks AB, Sweden.

One single tube is in one embodiment thread through more than one aperture without being joined to another tube part.

BRIEF DESCRIPTION OF THE DRAWINGS:

The invention will be described in more detail with reference to the accompanying drawings.

Figure 1	shows schematically a perspective view of a section taken diametrically through the stator of a rotating electrical machine.
Figure 2	shows a cross-sectional view of a high-voltage cable according to the present invention,
Figure 3	shows schematically a sector of a rotating electric machine,
Figure 4	shows a sector corresponding to a slot division in a stator tooth with its yoke as indicated by the broken lines in Figure 3,
Figure 5	shows an alternative sector corresponding to a slot division of a stator tooth with its yoke provided with axial cooling tubes in accordance with the present invention.
Figure 6	shows a cooling circuit in accordance with the present invention.
Figure 7	shows a combination of holes for an arrangement in accordance with the present invention.

Figure 8 shows an alternative arrangement of the holes in accordance with the present invention.

DESCRIPTION OF THE INVENTION:

Figure 1 shows part of an electric machine in which the rotor has been removed to show more clearly the arrangement of a stator 1. The main parts of the stator 1 constitute a stator frame 2, a stator core 3 comprising stator teeth 4 and a stator yoke 5. The stator also comprises a stator winding 6 composed of high-voltage cable situated in a space 7 shaped like a bicycle chain, see Figure 3, formed between each individual stator tooth 4. In Figure 3 the stator winding 6 is only indicated by its electric conductors. As can be seen in Figure 1, the stator winding 6 forms a end-winding package 8 on both sides of the stator 1. It is also clear from Figure 3 that the insulation of the high-voltage cables has several dimensions, arranged in groups depending on the radial position of the cables in the stator 1. For the sake of simplicity only one end-winding package is shown at each end of the stator in Figure 1.

In larger conventional machines the stator frame 2 often consists of a welded sheet steel construction. In large machines the stator core 3, also known as the laminated core, is generally formed of 0.35 mm core sheet divided into stacks with an axial length of approximately 50 mm, separated from each other by 5 mm ventilation ducts forming partitions. In a machine according to the present invention, however, the ventilation ducts are eliminated. In large machines each stack of laminations is formed by fitting punched segments 9 of suitable size together to form a first layer, after which each subsequent layer is placed at right angles to produce a complete plate-shaped part of a stator core 3. The parts and the partitions are held together by pressure legs 10 pressing against pressure rings, fingers or segments, not shown. Only two pressure legs are shown in Figure 1.

Figure 2 shows a cross-sectional view of a high-voltage cable 11 according to the invention. The high-voltage cable 11 comprises a number of strands 12 of copper (Cu), for instance, having circular cross section. These strands 12 are arranged in the middle of the high-voltage cable 11. Around the strands 12 is a first semiconducting layer 13, and around the first

semiconducting layer 13 is an insulating layer 14, e.g. XLPE insulation. Around the insulating layer 14 is a second semiconducting layer 15. Thus the concept "high-voltage cable" in the present application does not include the outer protective sheath that normally surrounds such cables for power distribution. The high-voltage cable has a diameter in the range of 20-200 mm and a conducting area in the range of 80-3000 mm^2.

Figure 3 shows schematically a radial sector of a machine with a segment 9 of the stator 1 and with a rotor pole 16 on the rotor 17 of the machine. It can also be seen that the high-voltage cable 11 is arranged in the space 7 in the shape of a bicycle chain, formed between each stator tooth 4.

Figure 4 shows a tooth sector 18 corresponding to one slot pitch indicated by the broken lines extending radially in Figure 3, defining the tooth height as the radial distance from the tip 19 of a tooth to the outer end 20 of the space 7 resembling a bicycle chain. The length of a stator tooth is thus equivalent to the tooth height. Furthermore, the yoke height is defined as the radial distance from the outer end 20 of the space 7 resembling a bicycle chain, to the outer end 21 of the stator core 3. This latter distance denotes the width of an outer yoke portion 22. A tooth waist 23, furthermore, is defined as being one of several narrow parts formed along each stator tooth by the space 7 resembling a bicycle chain between the stator teeth. Thus a number of tooth maxima 24 are formed radially between each tooth waist 23, their dimensions increasing from a smallest maximum nearest the tooth tip 19 and a largest maximum nearest the outer end 20 of the space 7 resembling a bicycle chain. As is clear from the figure, the width of the outer yoke portion in the sector shown increases towards the outer edge 21 of the stator core 3.

In a high-voltage rotating electric machine of the type described above at least one stator tooth 4 is provided according to the present invention, see Figure 5, with at least one cooling duct running substantially axially, preferably in the form of a cooling tube 25, connected to a cooling circuit in which coolant is arranged to circulate. In a possible embodiment the cooling ducts may use oil as coolant. To achieve efficient cooling, cooling ducts/tubes are preferably arranged in every stator tooth. According to the embodiment of the invention shown in Figure 5 four cooling tubes are

arranged to run axially through the actual tooth, whereas another two cooling tubes are arranged to run axially through the outer yoke portion 22 of the sector shown. As can be seen in the figure, two narrow cooling tubes may be arranged beside each other instead of a single thicker one, in at least one tooth maximum. Each of these two tubes belongs to its own parallel coolant circuit. The advantage is that narrower cooling tubes are more easily bent to a smaller radius. Another advantage of narrow tubes is that these do not obstruct the magnetic flux to the same extent as a thick tube. This advantage is also gained with elliptical and oval tubes with their large axis in the radial direction of the tooth. According to one embodiment, all tooth maxima are provided with double cooling tubes and all the cooling tubes in a slot pitch sector are radially aligned. According to another embodiment cooling tubes in a slot pitch sector are also radially aligned. The cooling also occurs on the earth potential in all embodiments.

Other embodiments with cooling tubes arranged in conjunction with the stator winding 6 also lie within the scope of the appended claims, e.g. cooling tubes placed between the windings in a triangular space 26 in the form of attachment elements to the windings, for instance, or in specially provided grooves in a tooth side 27.

Each cooling tube 25 is provided with an insulating layer 28 in order to avoid contact with the metal in the stator tooth 4 or in the outer yoke portion 22. A thermally conducting glue may alternatively be used for attachment. In another preferred embodiment each cooling tube 25 is made of a dielectric material such as a polymer, preferably XLPE, in order to avoid electrical contact with the metal in the stator tooth 4 or in the outer yoke portion 22. All cooling tubes are embedded in the apertures 28 running in the stator 1 with a cold-vulcanized, two-component silicon rubber provided with filler to increase the thermal conductivity. The filler material is pressed into the apertures 28 after that the tube 25 has been mounted. The filler material is also arranged to be pressed into the aperture 28 from one side of the stator with overpressure before hardening.

All cooling tubes 25 are connected to a closed cooling circuit 29, see Figure 6, which in the embodiment shown comprises a tank 30 containing coolant 31 which may be water, hydrogen gas or other coolant for the circuit. The tank 30 is provided with a level indicator for control and monitoring of the coolant level. The tank 30 is also connected to two annular conduits consisting of an inlet loop 32 and an outlet loop 33. Between the inlet loop 32 and outlet loop 33 a number of parallel circuits are connected, the number generally corresponding to the number of stator teeth or tooth sides provided with cooling tubes, of which one parallel circuit 34 is shown in Figure 6. The coolant 31 is arranged to circulate from the inlet loop 32 simultaneously through every parallel circuit 34 to the outlet loop 33 and on to a circulation pump 35 and a circulation filter 36 through a heat exchanger 37, i.e. a plate heat exchanger, and then back to the inlet loop 32. Water from a water reservoir is supplied through one end of the heat exchanger 37 via the exchanger filter, not shown, of an exchanger pump 38. The water is pumped through the exchanger and back to the water reservoir.

Figure 7 is showing an alternative design of the cooling tubes 25 placed in a eight-formed double hole 39. This arrangement makes it possible to combine two cooling tubes 25 in this hole in a tooth maximum 24 in the stator tooth as is showed in figure 8. Furthermore, the double hole arrangement is radially aligned as is also showed in figure 8.

When manufacturing a stator cooled in accordance with the present invention, the first cooling circuit 29 is dimensioned taking into consideration possible distances between the cooling tubes 25. The distance between tubes must be chosen so that they can be placed in the middle of the broadest parts of the stator tooth 4 at a tooth maximum 24. This is important from the magnetic point of view in order to avoid magnetic saturation in the stator teeth. A thermal calculation is performed in order to ensure the correct number of tubes, with radial and axial spacing so that a uniform temperature distribution is obtained in the high-voltage cables. The apertures are inserted in the punching template for the stator laminations and no additional operation is thus required. The cooling tubes 25, preferably of stainless steel, are inserted after the laminations have been stacked but before the stator is wound. The tubes

are first insulated and glued in the apertures by pressurizing the glue and inserting the tubes from below. The tubes may be spliced by means of welding. However, an electrically insulating tube part must be provided in each parallel circuit 34. This can be achieved by choosing tubes of polymer material for the connections to the ring circuits 32, 33 above the generator.

The tubes must be embedded since the thermal resistance between the tube and the stator core will otherwise be too high. In order to increase heat transfer between tube and stator core, the space is filled with a cross-linkable casting compound. This may consist of a polymer which has low viscosity and can therefore withstand being filled with a high content of heat-conducting filler material before being injected into the space where it is converted through chemical reaction to a non-fluid compound. Examples of suitable compounds are acryl, epoxy, unsaturated polyester, polyurethane and silicon, the latter being preferred since it is non-toxic. Heat-conducting filler may also comprise oxides of aluminium, magnesium, iron or zinc, nitrides of boron or aluminium, silicon carbide.

The embedding compound may be a silicon rubber, i.e. a mixture of for instance aluminium oxide and silicon, i.e. polydimethyl siloxane with vinyl groups which react with hydrogen polydimethyl siloxane in the presence of a platinum catalyst. This is forced into the aperture 28 between the XLPE tube and the stator core at over-pressure, after which curing occurs by the hydrogen atoms being added to the vinyl groups.

A magnetic flux flows between the cooling tube and earth which would induce a circulating current if the tube were uninsulated from the metal laminations. The tube insulation should be thin but at the same time so resistant to wear that the tube can be inserted into the aperture without damage to the insulation. The tube could be coated with a layer of varnish or wound with insulating fabric.

One single tube 25 is arranged to be tread through more than two aperture 28 without being jointed to another tube part. U-shaped tubes may be used in order to reduce the number of joints in the cooling tubes. Welding is the

preferred splicing method but other solutions are possible such as O-rings, couplings, glueing, soldering, etc.

The invention is not limited to the embodiments shown by way of example. Several modifications are feasible within the scope of the invention. Thus the tubes in each slot division need not be connected in series but may sometimes be connected in parallel. Similarly, several slot divisions may be arranged in series. The joints may be performed in several different ways, e.g. soldering welding, screwed joint elements, tube clamps, etc. The cooling circuit need not be connected as shown in Figure 6. Instead it may be open, in which case the heat exchanger is eliminated. The glue can be introduced by other means that under pressure depending, for instance, on its viscosity. Finally, the tubes may be made of different material, even polymer material, depending on the need for tube insulation.

CLAIMS

1. A rotating electric machine, comprising a stator and at leased one winding), characterized in that the machine comprises a winding comprising a isolation system including at least two semiconducting layers, each layer constituting essentially an equipotential surface and also including solid isolation disposed therebetween, and that at least one stator tooth (4) in a tooth sector (18) is provided with at least one cooling duct running substantially axially and connected to a cooling circuit (29) in which coolant (31) is arranged to circulate.

2. A machine as claimed in claim 1, characterized in that at least one of the layers has substantially the same coefficient of thermal expansion as the solid insulation.

3. A machine as claimed in claim 1 or 2, characterized in that the cooling duct is arranged inside a stator tooth (4).

4. A machine as claimed in claim 3, characterized in that the cooling duct consists of a cooling tube (25).

5. A machine as claimed in claim 4, characterized in that each stator tooth (4) is provided with at least one axially-running cooling tube (25) connected to a cooling circuit (29) in which coolant (31) is arranged to circulate.

6. A machine as claimed in either of claims 4-5, characterized in that each tooth sector (18) is provided with at least four axially-running cooling tubes (25), of which at least three cooling tubes (25) are arranged to run in the stator tooth (4) and the remaining cooling tubes (25) are arranged to run in the outer yoke portion (22).

7. A machine as claimed in claim 6, characterized in that the cooling tubes (25) arranged in the stator tooth (4) are arranged centrally in a tooth maximum (24) in the stator tooth (4).

8. A machine as claimed in any of claims 4-7, characterized in that all the cooling tubes (25) are electrically insulated from the stator (1) by means of an insulating layer (28).

9. A machine as claimed in claim 8, characterized in that all the cooling tubes (34) are glued to the stator (1) with thermally conducting glue.

10. A machine as claimed in either of claims 8-9, characterized in that all the cooling tubes (25) pertaining to one and the same tooth sector (18) are oriented radially in line with each other.

11. A machine as claimed in any of claims 1-10, characterized in that the cooling circuit (29) is provided with an insulating section.

12. A method of cooling a rotating electric machine provided with high-voltage stator windings, characterized in that the stator is cooled by a coolant (31) being caused to circulate in a cooling circuit (29) through cooling ducts running axially through the stator teeth (4).

13. A method as claimed in claim 12, characterized in that the coolant (31) is caused to circulate in a closed circuit which passes through a heat exchanger (37) cooling the circuit (29) with water from a water reservoir.

14. A rotating electric high voltage machine comprising stator, rotor and at least one winding, characterized in that said winding comprises at least one current-carrying conductor, a first layer having semiconducting properties provided around said conductor, a solid insulating layer provided around said first layer, and a second layer having semiconducting properties provided around said insulating layer, and that at least one stator tooth (4) in a tooth sector (18) is provided with at least one cooling duct running substantially axially and connected to a cooling circuit (29) in which coolant (31) is arranged to circulate.

15. A rotating machine according to claim 14, c h a r a c t e r i z e d i n t h a t the potential of said first layer is substantially equal to the potential of the conductor.

16. A rotating machine according to claim 14 or 15, c h a r a c t e r i z e d i n t h a t said second layer is arranged to constitute substantially an equipotential surface surrounding said conductor.

17. A rotating machine according to claim 16, c h a r a c t e r i z e d i n t h a t said second layer is connected to a predetermined potential.

18. A rotating machine according to claim 17, c h a r a c t e r i z e d i n t h a t said predetermined potential is earth potential.

19. A rotating machine according to any one of the claims 14, 15, 16, 17 or 18, c h a r a c t e r i z e d i n t h a t at least two adjacent layers have substantially equal thermal expansion coefficients.

20. A rotating machine according to any one of claims 14-19, c h a r a c t e r i z e d i n t h a t said current-carrying conductor comprises a number of strands, only a minority of said strands being non-isolated from each other.

21. A rotating machine according to any one of claims 14-20, c h a r a c t e r i z e d i n t h a t each of said three layers is fixed connected to adjacent layer along substantially the whole connecting surface.

22. A rotating electric machine having a magnetic circuit for high voltage comprising a magnetic core and a winding, c h a r a c t e r i z e d i n t h a t said winding is formed of a cable comprising one or more current-carrying conductors, each conductor having a number of strands, an inner semiconducting layer provided around each conductor, an insulating layer of solid insulating material provided around said inner semiconducting layer, and an outer semiconducting layer provided around said insulating layer, and that at least one stator tooth (4) in a tooth sector (18) is provided with at least one cooling duct running substantially axially and connected to a cooling circuit (29) in which coolant (31) is arranged to circulate.

23. A rotating machine according to claim 22, characterized in that said cable also comprises a metal shield and a sheath.

24. A rotating electric high voltage machine comprising stator, rotor and windings, the rotor including an outer yoke portion (22), radially towards the centre protruding stator teeth (4) between which are formed tracks in which the windings are placed, characterized in that the stator teeth are arranged with a number of recesses so formed that every recess will be showing the form of the windings placed in slots therebetween and that axial placed cooling tubes (25) are mounted in the stator teeth, which cooling tubes are connected to a cooling circuit (29) in which cooling medium in gas or liquid phase is arranged to circulate and that the cooling tubes are radially located in the stator teeth between the recesses.

25. A rotating machine according to claim 24, characterized in that the said winding comprises at least one current-carrying conductor, a first layer having semiconducting properties provided around said conductor, a solid insulating layer provided around said first layer, and a second layer having semiconducting properties provided around said insulating layer.

26. A rotating machine according to any of claims 24-25, characterized in that the cooling tubes (25) are electrically insulated from the stator.

27. A rotating machine according to claim 26, characterized in that the cooling tubes (25) comprises tubes of dielectric material.

28. A rotating machine according to claim 26, characterized in that the cooling tubes (25) are electrically insulated from the stator by an insulating layer (28).

29. A rotating machine according to claim 27, characterized in that the cooling tubes (25) comprises tubes of non-circular cross-section.

30. A rotating machine according to claim 29, c h a r a c t e r i z e d i n t h a t the cooling tubes (25) comprises tubes of XLPE with oval cross-section.

31, A rotating machine according to any of claims 24-30, c h a r a c t e r i z e d i n t h a t the cooling tubes (25) are connected to the stator by a thermal conducting binding agent.

32. A rotating machine according to any of claims 24-30, c h a r a c t e r i z e d i n t h a t at least three cooling tubes (25) seen in a radial cross shape are arranged in the stator teeth and that the rest of the cooling tubes (25) are arranged in the yoke portion of the stator.

33. A rotating electric machine comprising a stator, rotor and at leased one winding (characterized in that the stator (1) is provided with at least one cooling tube (25) made of dielectric material and inserted in an aperture (28) running axially through the stator (1), said tube communicating with a coolant circuit (29) in which coolant (31) is arranged to circulate.

34. A machine as claimed in claim 33, characterized in that the cooling tube (25) is made of polymer material.

35. A machine as claimed in claim 33, characterized in that the cooling tube (25) is made of high-density polyethylene (HDPE).

36. A machine as claimed in claim 33, characterized in that the cooling tube (25) is made of cross-linked polyethylene (XLPE).

37. A machine as claimed in any of claims 33-36, characterized in that the cooling tube (25) is embedded in the aperture (28) in the stator (1) with a cross-linkable casting compound.

38. A machine as claimed in claim 37, characterized in that the cooling tube (25) is embedded in the aperture (28) with a filler material provided with two-component silicon rubber.

39. A machine as claimed in claim 37, characterized in that the filler material consists of either aluminium oxide, boron nitride or silicon carbide.

40. A machine as claimed in any of claims 33-39, characterized in that the cooling tube (25) is arranged inside at least one stator tooth (4).

41. A machine as claimed in claim 40, characterized in that each stator tooth (4) is provided with at least one axially running cooling tube (25) communicating with a coolant circuit (29) in which coolant (31) is arranged to circulate.

42. A machine as claimed in any of claims 33-41, characterized in that each tooth sector (18) is provided with at least four axially running cooling tubes (25), whereof at least three cooling tubes (25) are arranged to run in the stator tooth (4) and the remaining cooling tubes (25) are arranged to run in the outer yoke part (22).

43. A machine as claimed in any of claims 40-42, characterized in that the cooling tubes (25) disposed in the stator tooth (4) are arranged centrally in a tooth maximum (24) in the stator tooth (4).

44. A machine as claimed in any of claims 40-43, characterized in that all the cooling tubes (25) pertaining to one and the same tooth sector (18) are oriented in radial alignment with each other.

45. A machine as claimed in either of claims 43 or 44, characterized in that at least one tooth maximum is provided with two cooling tubes (25).

46. A machine as claimed in any of claims 33-45, characterized in that the cooling tubes (25) have elliptical cross section.

47. A machine as claimed in any of claims 33-46, characterized in that the high-voltage cable (11) has a diameter in the range of 20-200 mm and a conducting area in the range of 30-3000 mm^2.

48. A machine as claimed in any of the preceding claims, characterized in that the filler material is pressed into the aperture (28) after that the tube (25) has been mounted.

49. A machine as claimed in any of the preceding claims, characterized in that the filler material is arranged to be pressed into the aperture (28) from one side of the stator with overpressure before hardening.

50. A machine as claimed in claim 33, characterized in that the cooling tube (25) is made of polyethylene (PE).

51. A machine as claimed in any of the preceding claims, characterized in that one single tube (25) is arranged to be tread through more than two aperture (28) without being jointed to another tube part.

52. A machine as claimed in any of claims 45-51, characterized in that the apertures (28) are formed as an eight shaped double hole (39).

Fig. 1

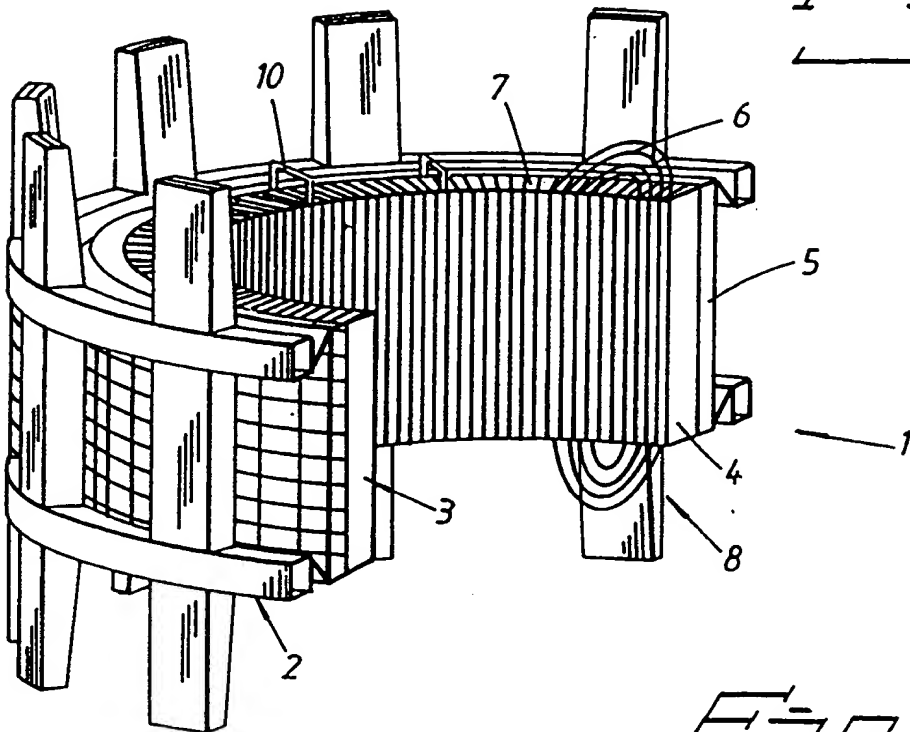


Fig. 3

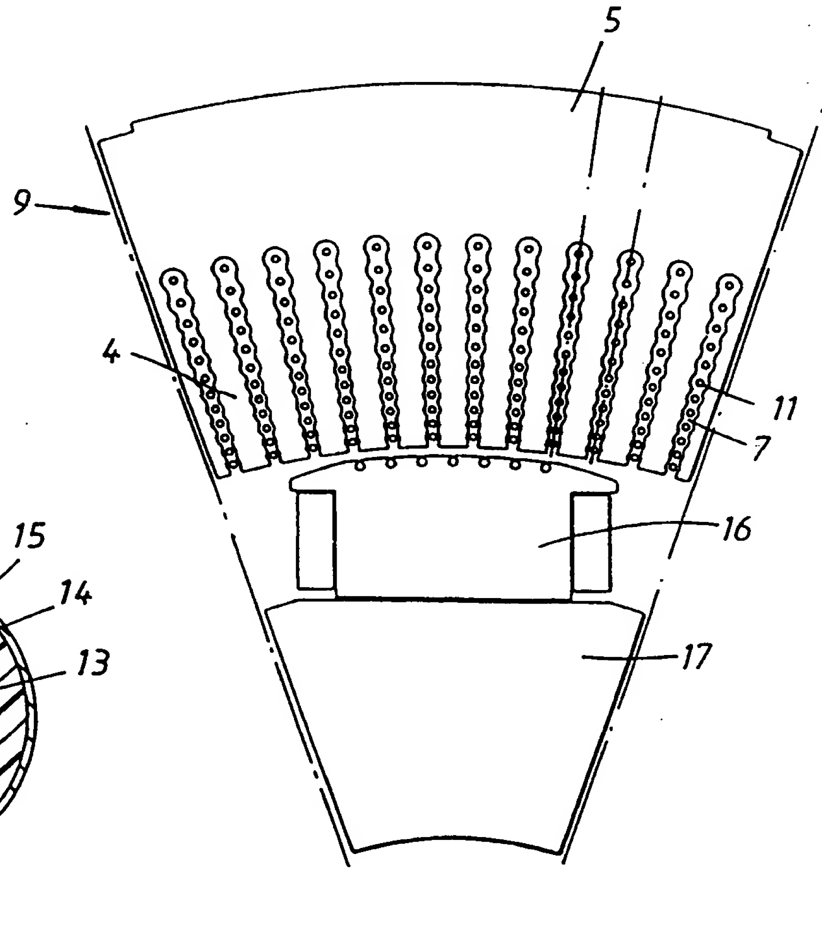


Fig. 2

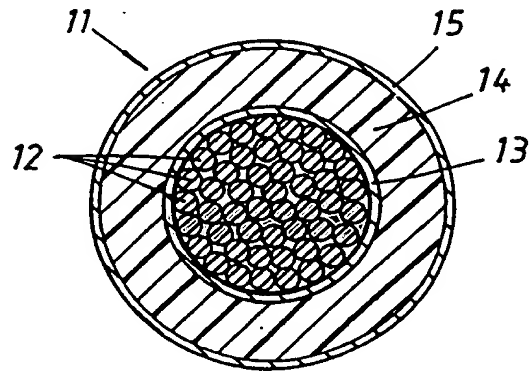


Fig. 4

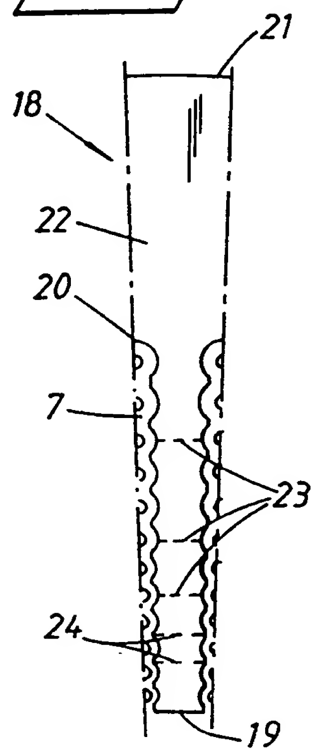


Fig. 5

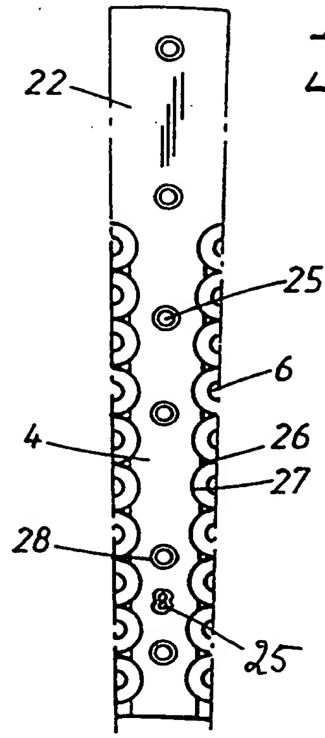
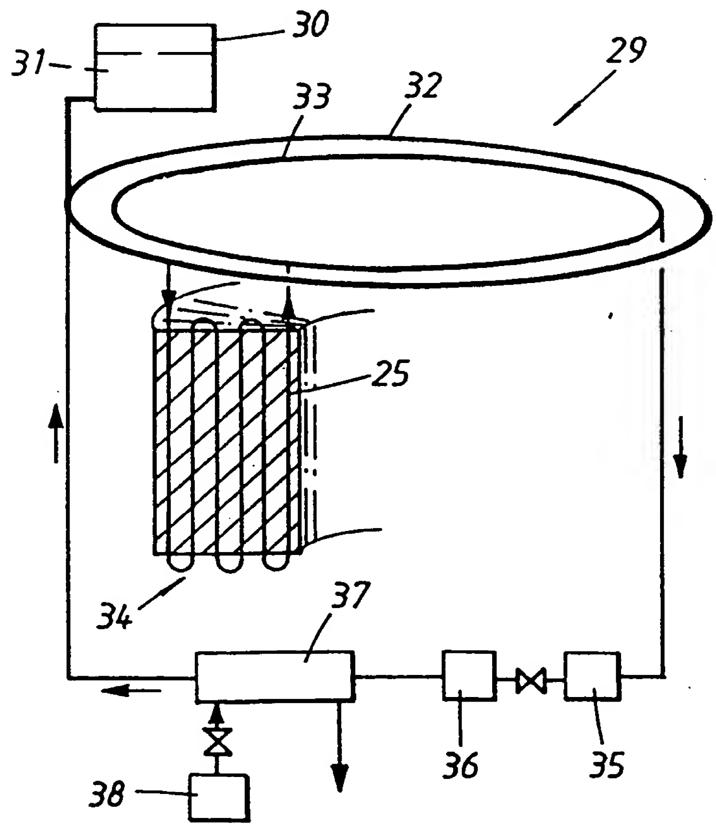


Fig. 6



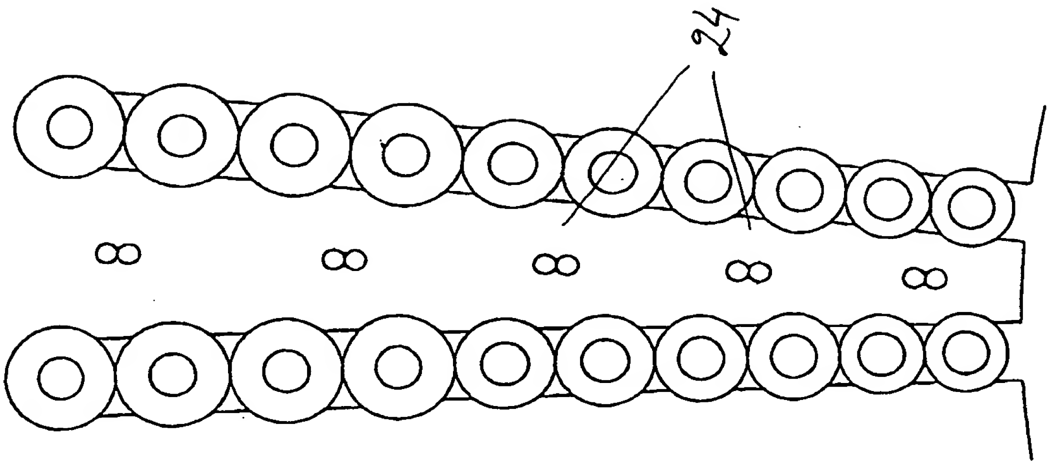


Fig. 8

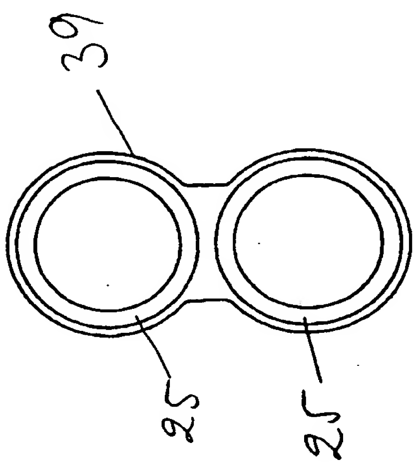


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00893

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 1/20, H02K 3/40, H02K 15/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5036165 A (R.K. ELTON ET AL.), 30 July 1991 (30.07.91), see the whole document --	1-11,14-21, 22-23,25
Y	US 4853565 A (R.K. ELTON ET AL.), 1 August 1989 (01.08.89), column 5, line 55 - line 61; column 7, line 12 - line 37, figures 4,7 --	1-11,14-21, 22-23,25
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X	 --	12-13

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" erlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 Sept 1997	07-10- 1997

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00893

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 2975309 A (M. SEIDNER), 14 March 1961 (14.03.61), see the whole document	1-11,14-21, 22-23,24-32, 33-52
X		12-13
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Information on patent family members

01/09/97

International application No.
PCT/SE 97/00893

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